Ultrafast Narrow-Band Modulation of VCSELs

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Quantum Optoelectronics

Outline

- Introduction (application and generation)
- Model and Equations
- Coupled VCSELs
- Multi-Transverse Mode Dynamics
- Modulation of Multimode VCSELs
- Extension of Bandwidth
- Conclusion

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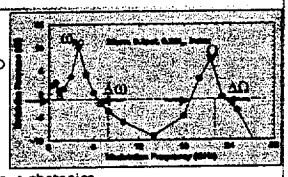
Introduction: Application

High-Frequency: $\Omega >> \omega_{RO}$

Narrow Band: $\Delta\Omega << \Omega$

(digital application: $\omega_{RO} \sim \Delta\omega$)



- Microwave, millimeter-wave photonics
- Narrow-band communications
- All-optical clock generation and recovery
- Digital communication, if bandwidth $\Delta\Omega$ expanded

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Introduction: Generation

- Modulation of mode-locked (-coupled) lasers at 100GHz (theory, Lau 1988,1990)
- Resonant enhancement by feedback (experiment, Lau and Yariv 1985) or by external cavity (Nagarajan et al 1993)
- Push-pull modulated DFB lasers (theory, Marcenac et al 1994)
- Detuned DBR lasers (theory, Feiste 1998)
- 2-Section DBR lasers (theory and experiment, Kjebon et al 1997, Morthier et al 2000)
- Coupled VCSELS (theory, Ning and Goorjian, 2001)

Common features:

- Generating a second resonance in addition to the RO oscillation either through external cavity, feedback or multimode beating
- Using multi-section DBR or DFB lasers or needing external cavity or feedback

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Model and Equations

$$\frac{n_g}{c}\frac{\partial E}{\partial t} = \frac{i}{2K}\nabla^2 E - \kappa E + \frac{iK\Gamma}{2\varepsilon_0\varepsilon_b}P + \frac{i\delta n(x,y)}{n_b}KE$$

$$\frac{\partial N}{\partial t} = \nabla D\nabla N - \gamma N + \eta\frac{J(x,y,t)}{e} + \frac{iL\Gamma}{8\hbar}(P^*E - PE^*)$$

$$\frac{dP_j}{dt} = \{-\Gamma_j(N) + i[\delta_0 - \delta_j(N)]\}P_j - i\varepsilon_0\varepsilon_b A_j(N)E$$

$$(P = P_0 + P_1 + \ldots)$$

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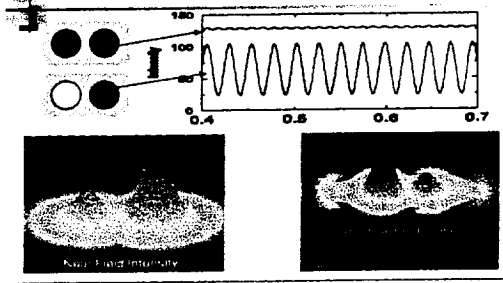
Coupled VCSELS: 40GHz Modulation



Ning and Goorjian, JAP 90,4974(2001)

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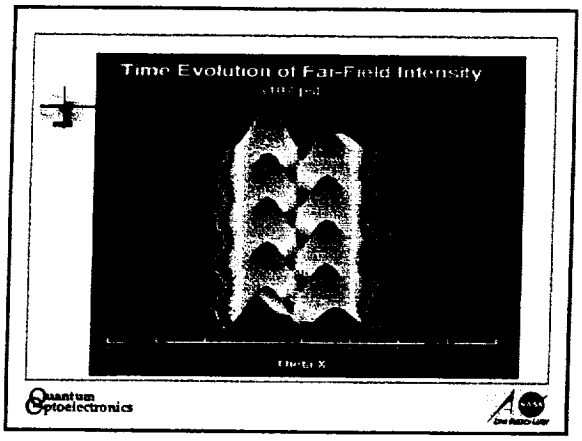
Time Evolution of Far-Field Intensity
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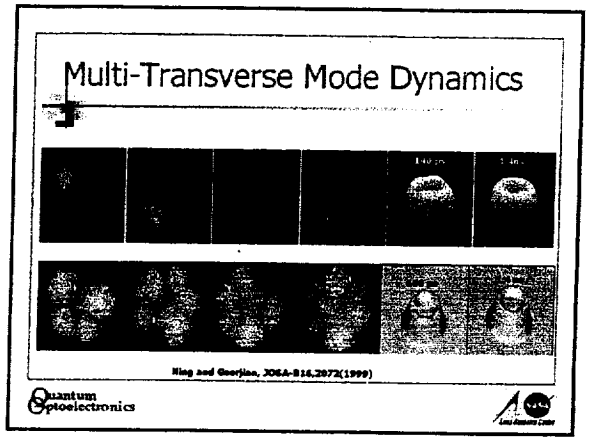
Multi-Transverse Mode Dynamics
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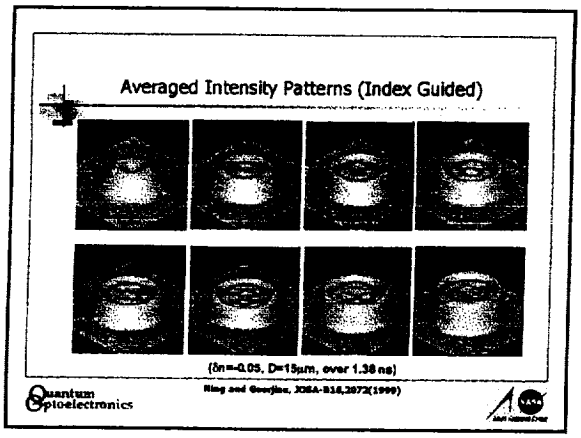
Averaged Intensity Patterns (Index Guided)
(δn=-0.05, D=15μm, over 1.38 ns)
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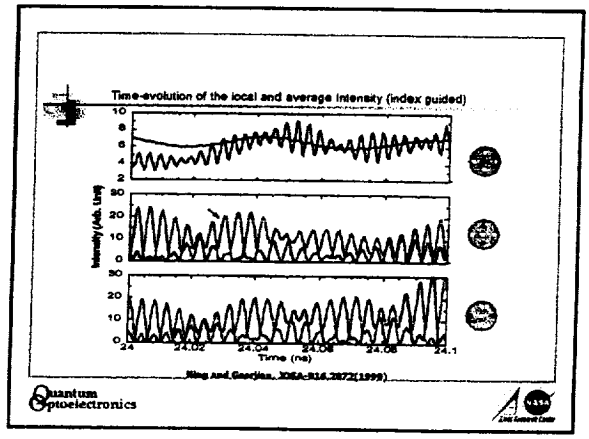
Time-evolution of the local and average intensity (index guided)
Time (ns)
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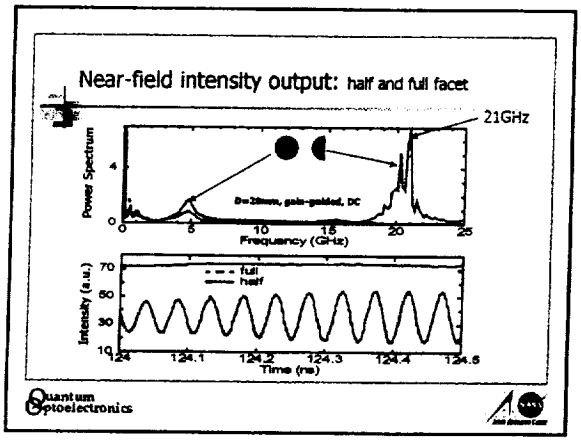
Near-field intensity output: half and full facet
21GHz
Power Spectrum
Frequency (GHz)
full
half
Intensity (a.u.)
Time (ns)
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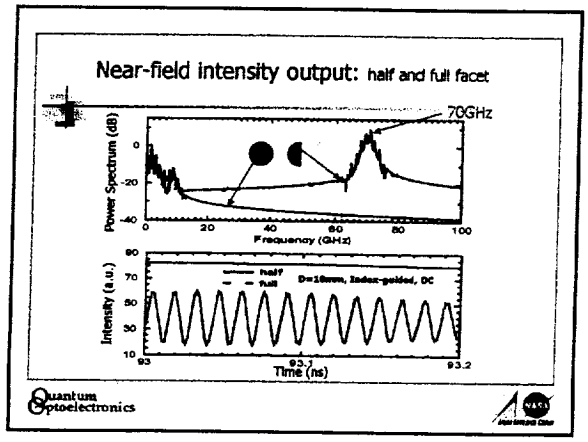
Near-field intensity output: half and full facet
70GHz
Power Spectrum (dB)
Frequency (GHz)
half
full
Intensity (a.u.)
Time (ns)
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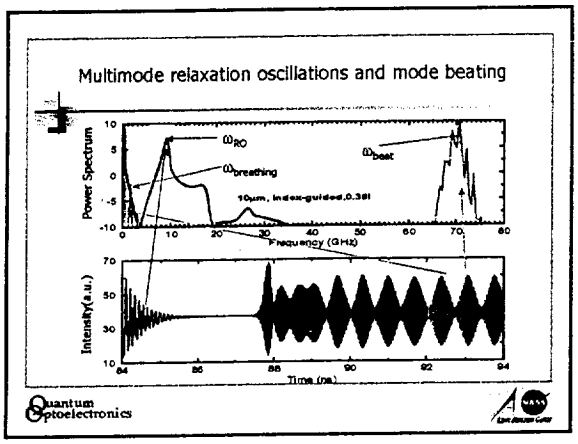
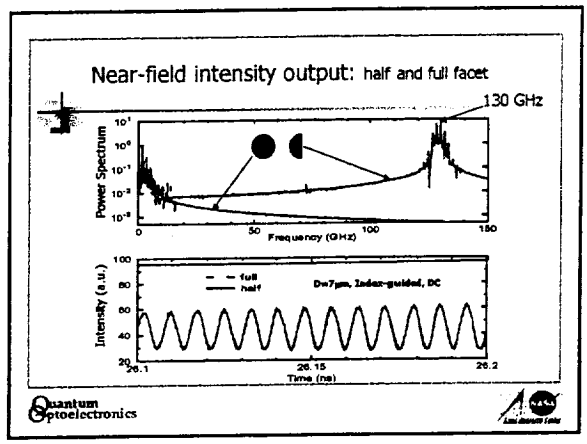
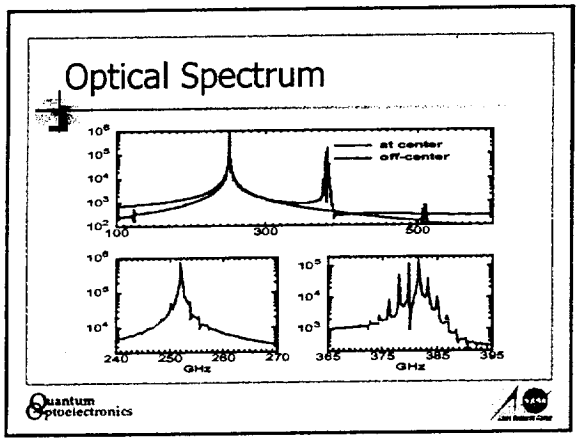

Multimode relaxation oscillations and mode beating
Power Spectrum
Frequency (GHz)
Intensity(a.u.)
Time (ns)
Quantum Optoelectronics


Near-field intensity output: half and full facet
130 GHz
Power Spectrum
Frequency (GHz)
Intensity (a.u.)
Time (ns)
Quantum Optoelectronics


Optical Spectrum
at center
off-center
GHz
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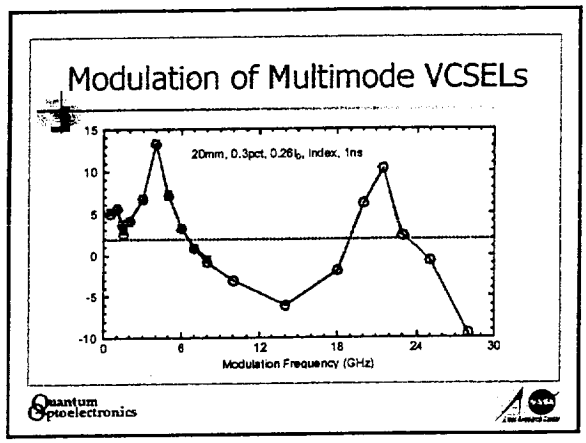
Modulation of Multimode VCSELs
20mm, 0.3pct, 0.26
Modulation Frequency (GHz)
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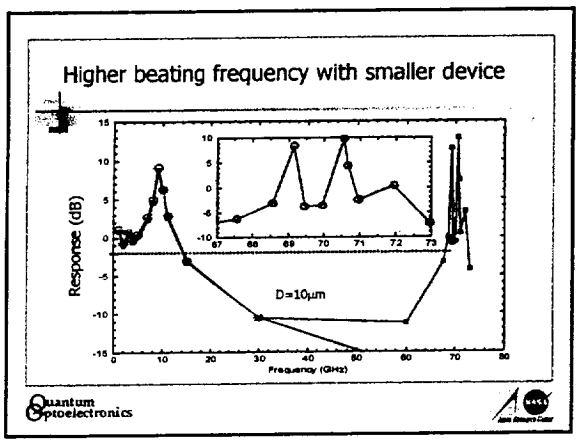
Higher beating frequency with smaller device
Response (dB)
D=10μm
Frequency (GHz)
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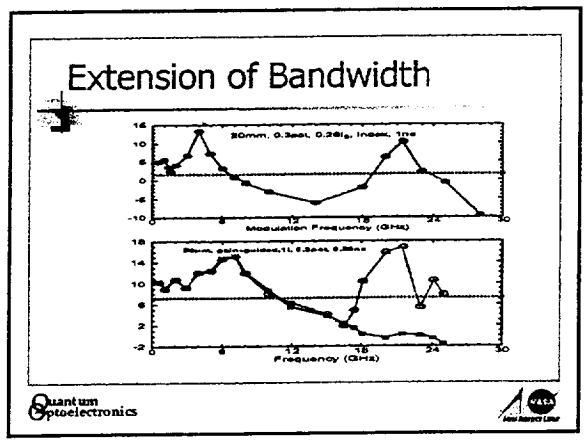
Extension of Bandwidth
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Conclusion

- Multimode beating greatly enhanced by taking output from part (e.g.,half) of output facet
- Simpler sources of microwave, millimeter wave of various frequencies generated by varying VCSEL diameter in a single multimode VCSEL or coupling of a few VCSELs
- Breathing frequency in multi-mode operation affects modulation response and bandwidth
- Optimizing RO frequency and mode beating frequency could potentially expand bandwidth suitable for wide band digital communication

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